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Risk Prioritization using TOPSIS in Elevated Metro Construction Project

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Abstract - *Owing to the rapid expansion of metro construction, the mishap frequency has amplified in recent years. Accidents and fatalities are mostly due to the direct or indirect involvement of unskilled workers, unawareness of safety regulations, random working environments and most prominently, a nonexistence of progressive safety control skills and tools which can recognize dangerous behaviors and unstable essential elements. A lot of present metro rail transit lines develop elevated structures as they signify every now and then the only option in densely packed built-up urban regions. The research uses Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) which is a multi-criteria decision analysis method (MCDA) to prioritize the identified hazards on the basis of their risk ranking obtained in HIRAC. The results obtained from the analysis is to be used for drafting hazard specific control measures and recommendation.*

Key Words: **Hazard Identification, Risk Assessment, Metro Construction, Work zone safety, TOPSIS**

1.INTRODUCTION

1.1 Transport network in India

The unwelcomed concentration of population in metropolitan cities have burdened the public transportation which plays an indispensable role in public commutation. Cities with un-organized public transportation system have led to a rapid upsurge in private ownership of vehicles, predominantly two-wheelers with consequential effects on pollution mutually noise & air. In maximum towns two-wheelers encompass more than 70 % of entire motor vehicles. Moreover, the physical infrastructure has not stood to cling to the pace with the progress in demand. 1.2 Mass Rapid Transit System (MRTS)

1.2 Background of Metro Construction

Metro construction in urban over-populated cities is the most popular and widely used solution in an attempt to organize and manage the traffic. With metro as an alternative mode of transportation, the pressure on the road transportation system can be relieved.

But, metro construction is characteristically complex and is linked with considerable potential risks. With the concerns over public safety, the subject of safety risk investigation and management during the metro construction has developed to be a community concern. Many mishaps and uninvited events are connected to uncertainties concerning in situ ground situations, which results in complex and high-risk construction work. Therefore, it is vital to cultivate safety risk assessment systems in order to evade or mitigate these occurrences.

Owing to the rapid expansion of metro construction, the mishap frequency has amplified in recent years. Accidents and fatalities are mostly due to the direct or indirect involvement of unskilled workers, unawareness of safety regulations, random working environments and most prominently, a nonexistence of progressive safety control skills and tools which can recognize dangerous behaviors and unstable essential elements. A lot of present metro rail transit lines develop elevated structures as they signify every now and then the only option in densely packed built-up urban regions.

The rail centered MRTS which is supposed to be the paramount solution, is at present active in Metropolitan cities like Kolkata, Delhi, Mumbai and execution in good health to the fulfilment of local commuters. Succeeding the accomplishment, the new metro projects are also being constructed or are in the progressive stage of operation in a few towns: Kochi, Chennai, Hyderabad, Jaipur and Pune.

Three most widely used distinct options for mobility of metro are:

Underground metro

Elevated metro

Surface rail system

To select the best suitable metro system, an objective framework should be developed to aid the decision. According to different reports, elevated metro systems are not a feasible way out for areas densely packed and built-up. Whereas, direct and perceptible costs of an elevated alternative may be lower, the underground route is further cost-effective from a total price & full lifecycle perspective. It is furthermore alleged that the elevated metro stations lessen the motor-able width of streets to over 30% which in turn worsen the traffic and cause in jamming on the roads. The existing costs for construction of the elevated and underground metro system are Rs. 234 cr./km. and Rs. 614 cr./km. respectively. Nevertheless, it is huge investment, the deal in the underground metro might result in the drop on road user cost. However, in scarcity of land availability and/or in presence of a lot of unknown underground utility cables crisscrossing, the elevated metro is considered to be a decent choice of metro systems in the metropolises.

Li et al., (2018) adopted Safety risk identification system (SRIS) and Safety risk early warning system (SREWS) based on the Building Information Model (BIM) platform in the construction of metro project in China to monitor the safety risk and to build a database for risk identification.

Sousa & Einstein, (2012) used an integrated approach that combines geologic prediction model with a construction strategy decision model based on Bayesian Networks to analytically assess and minimize the risks associated with Porto Metro tunnel construction. The approach developed was first validated on the site of Porto Metro tunnel then it was used to assess the risk on the test site where the results showed that the approach can forecast variations in geology and that it recommends changes in construction strategy accordingly. However, the drawback of this approach is the requirement of initial data to calibrate the approach. The course of metro construction comprises multifaceted activities which are:

- Safety problems to neighboring buildings and covered up pipelines frequently occur because metro construction sites are always located in the centre of congested cities;
- Because the degree of safety risk and the affected working area change continuously throughout the process of construction, safety control needs to be based on both spatial and temporal data
- The safety standing of metro construction is subjective by geological conditions and soil behaviours because the working area of metro construction is underground/ elevated;

2. METHODOLOGY

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is one of the most widely used multi-criteria decision analysis method (MCDA) developed by Hwang & Yoon, (1981) which was later further developed by Yoon, (1987) and Hwang et al., (1993). TOPSIS works on the principal of selection of alternative closest to the ideal and farthest from the negative.

Here, the Ideal alternative is the best suitable attribute which may be maximum or minimum depending on the type of criteria. Whereas, Negative ideal alternative is the worst attribute value which can also be maximum or minimum depending on the type of criteria.

The conventional technique of TOPSIS is to pick out single positive ideal solution (PIS) and single negative ideal solution (NIS) of the problem, compute the distance from respectively substitute to PIS and NIS, then equate the ratio standards of the second distance to the sum of the two remoteness and develop the final ranking of the options.

In the research, TOPSIS approach is being used to rank the hazards on the basis of their risk with proper weightage. Therefore, the pre-requisite for applying this approach here is the hazard identification and risk assessment with ratings of severity (S), likelihood (L) and detectability (D). Table shows the ratings of severity (S), likelihood (L) and detectability (D) for three major operations during the construction of elevated metro.

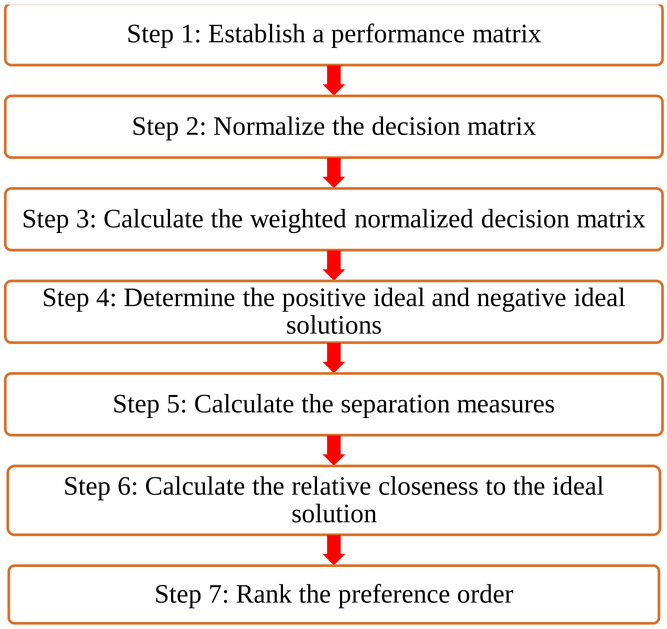

Figure 1: TOPSIS process flow chart

Step 1: Establish a performance matrix

The performance value of the alternatives is denoted by zij with respect to some attribute(A) / criterion (C);

$$\begin{array}{cc} & \begin{matrix} w_1 & w_2 & \cdots & w_n \\ C_1 & C_2 & \cdots & C_n \end{matrix} \\ M = \begin{pmatrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{pmatrix} & \begin{pmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & \cdots & z_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ z_{m1} & z_{m2} & \cdots & z_{mn} \end{pmatrix} \end{array}$$ Eq .(1)

Step 2: Normalize the decision matrix

The following transformation equation can be used to obtain the normalized performance matrix.

$$n_{ij} = \frac{z_{ij}}{\sqrt{\sum_{j=1}^{m} (z_{ij})^2}}$$ Eq .(2)

j= 1,.........,n, i=1,...........,m.

Step 3: Calculate the weighted normalized decision matrix

Since the weights of criteria in problem have different mean and importance. Therefore, the normalized value is computed as:

$$v_{ij} = w_j \times n_{ij}$$ Eq .(3)

The weight is computed by direct assignation by the author on the basis of the field experience.

Step 4: Determine the positive ideal and negative ideal solutions

The positive ideal and the negative ideal value set 'A' are computed as follows:

$$A^{+} = \{v_1^{+}, \ldots, v_n^{+}\} = \left\{\left(\max_i v_{ij},\ j \in J\right)\left(\min_i v_{ij},\ j \in J'\right)\right\} \quad \text{Eq.(4)}$$

$$A^{-} = \{v_1^{-}, \ldots, v_n^{-}\} = \left\{\left(\min_i v_{ij},\ j \in J\right)\left(\max_i v_{ij},\ j \in J'\right)\right\} \quad \text{Eq.(5)}$$

In the above equation, J is linked with benefit criteria, and J' is linked with Non-benefit criteria.

Step 5: Calculate the separation measures

The distance of each alternative from the positive ideal solution (PIS) A+ is:

$$d_i^{+} = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_j^{+}\right)^2\right\}^{\frac{1}{2}} \quad \text{Eq.(6)}$$

The distance of each alternative from the negative ideal solution (NIS) A- is:

$$d_i^{-} = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_j^{-}\right)^2\right\}^{\frac{1}{2}} \quad \text{Eq.(7)}$$

Step 6: Calculate the relative closeness to the ideal solution

The relative closeness "R", to the ideal solution can be expressed as:

$$R_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}}, \quad i = 1, \ldots, m \quad \text{Eq.(8)}$$

$$\text{If } \bar{R}_i = 1 \rightarrow A_i = \bar{A}^{+}$$
$$\text{If } \bar{R}_i = 0 \rightarrow A_i = \bar{A}^{-}$$

The closer the Ri is to 1, the higher the will be the priority.

Step 7: Rank the preference order

Rank the suitable alternative in decreasing order on the basis of Ri

3. RESULTS

The 34 identified potential hazards during the operation of Pile Boring, Concourse Pier Cap Erection and Steel Girder Erection are listed Table 1 along with their severity rating (S), likelihood rating (L) and detectability rating(D).

Table 1: Identified hazard and their severity, Likelihood and Detectability values

S No.	Task / Activity	Sub-Task	Hazards	(S)	(L)	(D)
1	Steel girder erection	Site Preparation	Settlement of soil / ground	2	1	1
2	Steel girder erection	Loading & Unloading of steel girder member from stacked point on multi axle trailers and from trailer to on ground.	Collapsing of trailer as well as crane due to inadequate capacity or any other external factor.	3	3	3
3	Steel girder erection	Assembly of Steel Girder	Collapsing of crane/Hydra due to inadequate capacity or any other external factor, Toppling of steel girder , Tripping hazard	3	2	4
4	Steel girder erection	Shifting /Transportation of girder	Failure of trailer, Other vehicular hazard.	3	4	4
5	Steel girder erection	Traffic Diversion	Constant movement of traffic will affect the proceeding of work and eventually turn into accident.	3	3	2
6	Steel girder erection	Electrical Management & Illumination	Struck by something, slip, trip fall or Electrocution.	4	3	4
7	Steel girder erection	Crane positioning at erection location.	Toppling of crane. Electrocution. Road side obstruction,	3	2	3
8	Steel girder erection	Lifting of steel girder segments.	Failure of Lifting tools and tackles. Breakdown of crane or toppling of crane, Oil spillage.	4	4	4
9	Steel girder erection	Hot work (Welding/Gas cutting) at height	Electrocution , Falling fireball / molten metal, tripping hazard	4	3	3
10	Steel girder erection	Deck slab	Unprotected leading edges, work platforms and access.	4	3	3
11	Steel girder erection	Working at Height	Unprotected leading edges, work platforms	4	3	3
12	Steel girder erection	Handling of Emergency situation	Failure of machine, slip/trip by person, electrocution, weather condition etc.	1	1	1
13	Concourse pier cap erection	Site Preparation at erection location.	Settlement of soil / ground	2	1	2
14	Concourse pier cap erection	Trestle Erection	Failure of trestle/ trestle members, Nut-bolts, Hydraulic/ mechanical jacks, hand tools/power tools or Fall of person	4	3	2
15	Concourse pier cap erection	Loading of CPC from stacked point on multi axle trailers.	Collapsing of Multy axel trailer as well as crane / Gantry crane due to inadequate capacity or any other external factor.	3	3	3

16	Concourse pier cap erection	Shifting /Transportation of CPC	Failure of Multy axel trailer, Other vehicle hazard.	3	4	3
17	Concourse pier cap erection	Traffic Diversion	Constant movement of traffic will affect the proceeding of work and eventually turn into accident.	3	3	3
18	Concourse pier cap erection	Electrical Management & Illumination	Struck by something, slip, trip fall or Electrocution.	4	3	3
19	Concourse pier cap erection	Crane positioning at erection location.	Toppling of crane. Electrocution. Road side obstruction,	3	2	3
20	Concourse pier cap erection	Lifting of CPC	Failure of Lifting tools and tackles. Breakdown of crane or toppling of crane, Oil spillage.	4	4	4
21	Concourse pier cap erection	Hot work (Welding/Gas cutting) at height	Electrocution , Falling fireball / molten metal, tripping hazard	4	3	3
22	Concourse pier cap erection	Concreting work for stitching of segments	Unprotected leading edges, work platforms and access, failure of equipment, falling of tools, falling of man etc.	4	3	3
23	Concourse pier cap erection	Stressing Work	Falling of jacks or tools or related accessories or failure of man lift or scaffolding materials or Spillage of oils or falling of person etc	4	3	2
24	Concourse pier cap erection	Grouting Work	Failure of Grouting machine, falling of slurry on engaged workmen or on ground from height.	3	2	2
25	Concourse pier cap erection	Working at Height	Unprotected leading edges, work platforms	4	3	2
26	Concourse pier cap erection	Handling of Emergency situation	Failure of machine, slip/trip by person, electrocution, weather condition etc.	1	1	1
27	Pile boring	Mobilization of equipment/ machinery, Surface preparation and positioning of Boring RIG	Excavator hit to personal/ vehicle, equipment failure, person injured during machine and equipment movement, machine topples.	4	3	3
28	Pile boring	Drilling by boring Rig & Liner fixing.	Personal injured by auger, rig hit the personal /equipment during swinging, falling hazards	3	2	2
29	Pile boring	Steel Fixing and Cage fabrication	Steel fall on the personal during shifting, cut , electric shock, tripping while cage fabrication or shifting.	2	2	2
30	Pile boring	Cage Lowering and trimme pipe fixing.	Hydra/ crane hit to the personnel, material fall on the personal, damage due to fall, equipment failure, damage to lifting hook.	3	2	3
31	Pile boring	Welding and gas cutting activity for Cage welding	Burn, fire, electrocution	1	1	1
32	Pile boring	Concreting of pile	TM hit to or fall on the personnel, equipment failure, Concrete hopper , trimme hit the personnel	3	2	2
33	Pile boring	Removal of liner and back filling	Hydra, crane and backhoe loader hit to the personnel, material fall on the personnel or damage due to fall/ mishandling, equipment failure, jerk load, damage to lifting hook.	4	3	3
34	Pile boring	Emergency evacuation procedure	Personal injured by vehicle or other reason (slip, trip, fall, illness etc.)	1	1	1

After determining the severity rating (S), likelihood rating (L) and detectability rating(D) of the identified hazards, the next step is to categorized them on the basis of beneficiary criteria. Since lower value of severity rating (S) and likelihood rating (L) is desirable, hence they come under Non-beneficiary criteria whereas higher value of detectability rating(D) is desirable, hence it comes under Beneficiary criteria. Also, proper weightage is assigned to severity rating (S)= 0.4, likelihood rating (L)=0.3 and detectability rating (D)=0.3.

The next step involves computation of Normalize the decision matrix using Eq.(2). Table 2 below shows the Normalize the decision matrix computed using the values obtained in Table 1

Table 2: Normalized and Weighted normalized decision matrix

	Normalize the decision matrix			Weighted normalized decision matrix		
	Non-beneficiary	Non-beneficiary	Beneficiary	Non-beneficiary	Non-beneficiary	Beneficiary
S No.	Severity (S)	Likelihood (L)	Detectability (D)	Severity (S)	Likelihood (L)	Detectability (D)
Cr-1	0.1058512	0.0637577	0.0625000	0.0423405	0.0191273	0.0187500
Cr-2	0.1587768	0.1912730	0.1875000	0.0635107	0.0573819	0.0562500
Cr-3	0.1587768	0.1275153	0.2500000	0.0635107	0.0382546	0.0750000
Cr-4	0.1587768	0.2550307	0.2500000	0.0635107	0.0765092	0.0750000
Cr-5	0.1587768	0.1912730	0.1250000	0.0635107	0.0573819	0.0375000
Cr-6	0.2117024	0.1912730	0.2500000	0.0846810	0.0573819	0.0750000

Cr-7	0.1587768	0.1275153	0.1875000	0.0635107	0.0382546	0.0562500
Cr-8	0.2117024	0.2550307	0.2500000	0.0846810	0.0765092	0.0750000
Cr-9	0.2117024	0.1912730	0.1875000	0.0846810	0.0573819	0.0562500
Cr-10	0.2117024	0.1912730	0.1875000	0.0846810	0.0573819	0.0562500
Cr-11	0.2117024	0.1912730	0.1875000	0.0846810	0.0573819	0.0562500
Cr-12	0.0529256	0.0637577	0.0625000	0.0211702	0.0191273	0.0187500
Cr-13	0.1058512	0.0637577	0.1250000	0.0423405	0.0191273	0.0375000
Cr-14	0.2117024	0.1912730	0.1250000	0.0846810	0.0573819	0.0375000
Cr-15	0.1587768	0.1912730	0.1875000	0.0635107	0.0573819	0.0562500
Cr-16	0.1587768	0.2550307	0.1875000	0.0635107	0.0765092	0.0562500
Cr-17	0.1587768	0.1912730	0.1875000	0.0635107	0.0573819	0.0562500
Cr-18	0.2117024	0.1912730	0.1875000	0.0846810	0.0573819	0.0562500
Cr-19	0.1587768	0.1275153	0.1875000	0.0635107	0.0382546	0.0562500
Cr-20	0.2117024	0.2550307	0.2500000	0.0846810	0.0765092	0.0750000
Cr-21	0.2117024	0.1912730	0.1875000	0.0846810	0.0573819	0.0562500
Cr-22	0.2117024	0.1912730	0.1875000	0.0846810	0.0573819	0.0562500
Cr-23	0.2117024	0.1912730	0.1250000	0.0846810	0.0573819	0.0375000
Cr-24	0.1587768	0.1275153	0.1250000	0.0635107	0.0382546	0.0375000
Cr-25	0.2117024	0.1912730	0.1250000	0.0846810	0.0573819	0.0375000
Cr-26	0.0529256	0.0637577	0.0625000	0.0211702	0.0191273	0.0187500
Cr-27	0.2117024	0.1912730	0.1875000	0.0846810	0.0573819	0.0562500
Cr-28	0.1587768	0.1275153	0.1250000	0.0635107	0.0382546	0.0375000
Cr-29	0.1058512	0.1275153	0.1250000	0.0423405	0.0382546	0.0375000
Cr-30	0.1587768	0.1275153	0.1875000	0.0635107	0.0382546	0.0562500
Cr-31	0.0529256	0.0637577	0.0625000	0.0211702	0.0191273	0.0187500
Cr-32	0.1587768	0.1275153	0.1250000	0.0635107	0.0382546	0.0375000
Cr-33	0.2117024	0.1912730	0.1875000	0.0846810	0.0573819	0.0562500
Cr-34	0.0529256	0.0637577	0.0625000	0.0211702	0.0191273	0.0187500
A+				0.0211702	0.0191273	0.0750000
A-				0.0846810	0.0765092	0.0187500

The next step involved the determination of distance of each alternative from the positive ideal solution (PIS) A⁺, d_i^+ and Negative ideal solution (NIS) A⁻, d_i^- using Eq (6) and Eq.(7) as shown in Table 3. Table 3 also shows the relative closeness (R_i)from the ideal solution for each alternative using Eq.(8). Then on the basis of R_i values, the alternatives are ranked.

Table 3: Distance of alternative from PIS and NIS

S No.	d_i^+	d_i^-	R_i	Rank	Mixed Rank
Cr-1	0.0601019	0.0713120	0.542652	27	11
Cr-2	0.0600641	0.0471199	0.439617	16	6
Cr-3	0.0464604	0.0712436	0.605278	33	14
Cr-4	0.0713120	0.0601019	0.457348	23	9
Cr-5	0.0682816	0.0341408	0.333333	4	2
Cr-6	0.0741419	0.0594131	0.444859	22	8
Cr-7	0.0501012	0.0576007	0.534816	24	10
Cr-8	0.0855938	0.0562500	0.396563	14	5
Cr-9	0.0764761	0.0420964	0.355027	5	3
Cr-10	0.0764761	0.0420964	0.355027	6	3
Cr-11	0.0764761	0.0420964	0.355027	7	3
Cr-12	0.0562500	0.0855938	0.603437	29	13
Cr-13	0.0430631	0.0737358	0.631306	34	15
Cr-14	0.0830860	0.0267846	0.243783	1	1
Cr-15	0.0600641	0.0471199	0.439617	17	6
Cr-16	0.0737358	0.0430631	0.368694	13	4
Cr-17	0.0600641	0.0471199	0.439617	18	6
Cr-18	0.0764761	0.0420964	0.355027	8	3
Cr-19	0.0501012	0.0576007	0.534816	25	10
Cr-20	0.0855938	0.0562500	0.396563	15	5
Cr-21	0.0764761	0.0420964	0.355027	9	3
Cr-22	0.0764761	0.0420964	0.355027	10	3
Cr-23	0.0830860	0.0267846	0.243783	2	1
Cr-24	0.0597061	0.0475726	0.443449	19	7
Cr-25	0.0830860	0.0267846	0.243783	3	1
Cr-26	0.0562500	0.0855938	0.603437	30	13
Cr-27	0.0764761	0.0420964	0.355027	11	3
Cr-28	0.0597061	0.0475726	0.443449	20	7
Cr-29	0.0471199	0.0600641	0.560383	28	12
Cr-30	0.0501012	0.0576007	0.534816	26	10
Cr-31	0.0562500	0.0855938	0.603437	31	13
Cr-32	0.0597061	0.0475726	0.443449	21	7
Cr-33	0.0764761	0.0420964	0.355027	12	3
Cr-34	0.0562500	0.0855938	0.603437	32	13

Table 4: Details of hazard on the basis of their ranking in descending order

S.NO	Hazard	Mixed Rank
Cr-14	Failure of trestle/ trestle members, Nut-bolts, Hydraulic/ mechanical jacks, hand tools/power tools or Fall of person	1
Cr-23	Falling of jacks or tools or related accessories or failure of man lift or scaffolding materials or Spillage of oils or falling of person etc	1
Cr-25	Unprotected leading edges, work platforms	1
Cr-5	Constant movement of traffic will affect the proceeding of work and eventually turn into accident.	2
Cr-9	Electrocution , Falling fireball / molten metal, tripping hazard	3
Cr-10	Unprotected leading edges, work platforms and access.	3
Cr-11	Unprotected leading edges, work platforms	3
Cr-18	Struck by something, slip, trip fall or Electrocution.	3
Cr-21	Electrocution , Falling fireball / molten metal, tripping hazard	3
Cr-22	Unprotected leading edges, work platforms and access, failure of equipment, falling of tools, falling of man etc.	3
Cr-27	Excavator hit to personal/ vehicle, equipment failure, person injured during machine and equipment movement, machine topples.	3
Cr-33	Hydra, crane and backhoe loader hit to the personnel, material fall on the personnel or damage due to fall/ mishandling, equipment failure, jerk load, damage to lifting hook.	3
Cr-16	Failure of Multy axel trailer, Other vehicle hazard.	4
Cr-8	Failure of Lifting tools and tackles. Breakdown of crane or toppling of crane, Oil spillage.	5
Cr-20	Failure of Lifting tools and tackles. Breakdown of crane or toppling of crane, Oil spillage.	5
Cr-2	Collapsing of trailer as well as crane due to inadequate capacity or any other external factor.	6
Cr-15	Collapsing of Multy axel trailer as well as crane / Gantry crane due to inadequate capacity or any other external factor .	6
Cr-17	Constant movement of traffic will affect the proceeding of work and eventually turn into accident.	6
Cr-24	Failure of Grouting machine , falling of slurry on engaged workmen or on ground from height.	7
Cr-28	Personal injured by auger, rig hit the personal /equipment during swinging, falling hazards	7
Cr-32	TM hit to or fall on the personnel, equipment failure, Concrete hopper , trimme hit the personnel	7
Cr-6	Struck by something, slip, trip fall or Electrocution.	8
Cr-4	Failure of trailer, Other vehicular hazard.	9
Cr-7	Toppling of crane. Electrocution. Road side obstruction,	10
Cr-19	Toppling of crane. Electrocution. Road side obstruction,	10
Cr-30	Hydra/ crane hit to the personnel, material fall on the Personal, damage due to fall, equipment failure, damage to lifting hook.	10
Cr-1	Settlement of soil / ground	11
Cr-29	Steel fall on the personal during shifting, cut , electric shock, tripping while cage fabrication or shifting.	12
Cr-12	Failure of machine, slip/trip by person, electrocution, weather condition etc.	13
Cr-26	Failure of machine, slip/trip by person, electrocution, weather condition etc.	13
Cr-31	Burn, fire, electrocution	13
Cr-34	Personal injured by vehicle or other reason (slip, trip, fall, illness etc.)	13
Cr-3	Collapsing of crane/Hydra due to inadequate capacity or any other external factor , Toppling of steel girder , Tripping hazard	14
Cr-13	Settlement of soil / ground	15

In general, the ranking of hazards covered all the important particulars in priority. The data. It is also evident from the casualty data obtained from different sources that these particular types of accidents are occurring on a regular basis during the construction stage.

The major causes of construction accidents from different sources included the following:

- Fall from heights
- Electrocution
- Fall of material

- Earth collapse
- Scaffold failure
- Miscellaneous

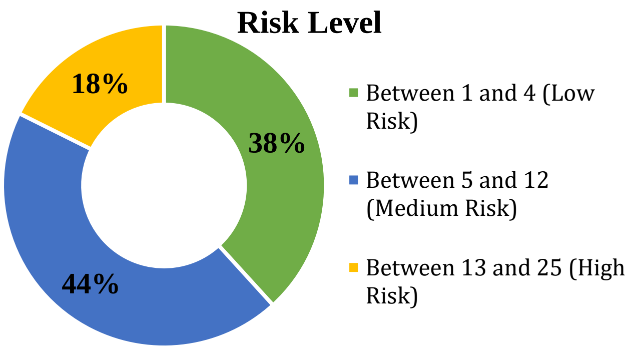

Figure 2: Distribution of risk level with proper weightage

4. CONCLUSIONS

The approach used in the methodology involves Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for ranking the identified hazards and the outcomes from this approach includes:

- The TOPSIS method adopted in the research was very simple and the calculations were easy to compute with the help M.S Excel.
- Though the alternatives or criteria were 34 in the research, TOPSIS proved out to be less time consuming and non-demanding.
- The drawback observed while using TOPSIS was reversal of ranking when a single alternative is added or removed.
- The identification of high ranked hazards having higher risk level using TOPSIS method aided in setting the priority of hazards to address first with proper control measures. Fall from heights, Electrocution, Fall of material, Earth collapse are few hazards that scored the highest in ranking.

The future work can include the assessment of human factor in accidents during construction of metro projects using different human error identification and reduction approaches.

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